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If no title is shown please refer to the description.  
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Percussive drill bit, drilling system comprising such a drill bit and method of  
drilling a bore hole

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PERCUSSIVE DRILL BIT, DRILLING SYSTEM COMPRISING SUCH A  
DRILL BIT AND METHOD OF DRILLING A BORE HOLE

The present invention relates to a percussion drill  
bit for drilling into a subterranean earth formation, the  
drill bit having a central longitudinal axis and being  
operable by applying repetitive axial percussive impacts  
in a direction having a component along the axis and  
rotary motion about the axis relative to the subterranean  
earth formation.

The invention further relates to a drilling system  
for drilling a borehole in an earth formation, comprising  
a drill string provided with such a percussion drill bit,  
and to a method of drilling a bore hole into a  
subterranean earth formation.

A percussive shearing drill bit is known and  
described in US patent 6,253,864. Figure 9 of said  
US patent depicts a percussive drill bit having dome  
shaped axial cutters optimised for percussive penetration  
of the earth formation, and shear cutters optimised for  
shear penetration.

In operation, the known percussive shearing drill bit  
is rotated about its longitudinal axis shearing off the  
rock formation as the drill bit rotates. A hammer  
simultaneously impacts the bit thereby providing an  
additional percussive drilling force. The shear cutting  
elements have been specially designed to withstand the  
unusual stresses induced by combined percussive/shear  
drilling, in that a distal portion of the shear cutter  
has been rounded to prevent large localised stresses in  
the cutters. Thus the shear cutting elements are  
optimised for both shearing and axial cutting.

It is an object of the invention to provide a percussion drill bit and a drilling system having a longer operational lifetime. It is also an object of the invention to provide a method for drilling a bore hole that consumes fewer percussion drill bits than before.

According to the invention, one or more of these objects is achieved in a percussion drill bit for drilling into a subterranean earth formation, the drill bit having a central longitudinal axis and being operable by applying repetitive axial percussive impacts on the drill bit in a direction having a component along the axis and by applying rotary motion about the axis relative to the earth formation, the drill bit comprising

- one or more axial cutters for predominantly axially cutting the subterranean earth formation in response to the axial percussive impacts;
- one or more shear cutters for predominantly shear cutting the subterranean earth formation in response to the rotary motion; whereby
- there is a first shear cutter of the one or more shear cutters, and whereby one or more of the axial cutters are arranged with respect to at least the first shear cutter to engage with the subterranean earth formation earlier during a percussive impact and/or deeper into the earth formation than at least the first shear cutter.

The drill bit according to the invention comprises axial cutters in addition to the shear cutters. The primary function of the axial cutters is to receive the percussive impacts between the drill bit and the earth formation, whereas the primary function of the shear cutters is to scrape off cutting debris from the bottom of the bore hole.

Since in accordance with the invention the axial cutters are arranged to engage with the earth formation

during the percussive impacts before at least said first shear cutter, the most intense part of the axial impacts accompanying the percussive motion is taken by the axial cutting elements. The percussive load on at least said first shear cutter is thereby reduced and consequently their operational lifetime is thereby improved. Thus the axial cutters effectively protect the shear cutter.

Alternatively, the axial cutters are arranged to penetrate the earth formation during the percussive impacts more than at least said first shear cutter.

Since the operational lifetime of the drill bit in accordance with the prior art was limited by the operational lifetime of the shear cutters, improvement of the operational lifetime of the shear cutters results in an improvement of the operation lifetime of the drill bit.

The effectiveness of the shear cutters is maintained at the same time, since the shear cutters are still arranged to engage with the earth formation towards the end of a percussive impact. Thus, the shear cutters become effective in response to rotary motion of the drill bit during which they scrape of cutting debris from the bottom of the bore hole.

As an additional advantage of the invention, the axial cutters can be optimised for axial cutting action, whereas the shearing cutters can independently be optimised for shear cutting without having to take into account axial cutting capability.

An advantageous way to arrange the axial cutters with respect to at least the first shear cutter to engage with the subterranean earth formation earlier in a percussive movement than at least the first shear cutter, is an arrangement whereby the one or more axial cutters are arranged with respect to the first shear cutter to penetrate on average deeper into the earth formation than

the first shear cutter in each percussive movement. This way, the axial cutters effectively pre-crush the rock and the bit is slowed down in the percussive movement at the same time.

5       The amount of deeper penetration that is desired depends on the hardness and type of the earth formation in which the bore hole is being drilled. The harder the rock, the higher is preferably the amount of penetration of the axial cutters relative to that of the first shear  
10 cutter. Preferably, the one or more axial cutters on average penetrate at least 1.5 times deeper into the earth formation than the first shear cutter in each percussive movement, more preferably at least 2 times deeper. This is found to be suitable for very hard  
15 formations including granite containing formations and black gneiss containing formations.

      An advantageous way to arrange the axial cutters with respect to at least the first shear cutter to engage with the subterranean earth formation earlier in a percussive  
20 movement than at least the first shear cutter, is an arrangement whereby the one or more axial cutters and the first shear cutter each have an impact point, defined as the part of the cutter that serves to firstly engage with the earth formation on an axial percussive movement,  
25 whereby at least the impact point of the first shear cutter is recessed by an amount of  $r$  in respect of the impact points of the one or more axial cutters. By simply recessing the shear cutter with respect to the one or more axial cutters, the latter will first engage the rock  
30 and thereby protect the shear cutter from the most intense part of the percussive impact.

      The first shear cutter is preferably protected by one or more axial cutters in relatively close vicinity of the first shear cutter, preferably by neighbouring axial  
35 cutters.

In a preferred embodiment, the first shear cutter is arranged in a first annular track about the central axis, the first annular track having a radial width corresponding to the radial width of the first shear cutter, and the one or more axial cutters are arranged in the first annular track. In this embodiment, the first shear cutter is optimally protected, since these axial cutters crush the rock in the same area as the first shear cutter becomes effective after rotation of the drill bit.

There can be a second shear cutter arranged in a second annular track about the central axis, the second annular track having a radial width corresponding to the radial width of the second shear cutter, whereby one or more axial cutters are arranged in the second annular track. In order to achieve a constant rate of penetration of the drill bit in both tracks, the amount of rock that is to be removed per cutter in each track can vary from track to track depending on the area covered by the track and the number of cutters in the track concerned. In particular in such cases, it is preferred that the impact point of the second shear cutter is recessed in respect of the impact points of the one or more axial cutters in the second annular track by an amount larger than  $r$ .

The number of axial cutters in relation to the number of shear cutters can be optimal in dependence of the type of earth formation to be drilled. Earth formations containing relatively hard rock, such as granite, can be drilled with relatively fewer shear cutters and greater total number of cutters, thereby distributing the percussive impact over a larger number of axial cutters.

A softer formation, such as a lime stone or a sand stone, is best drilled using a bit having relatively many shear cutters because impact forces are lower and the chance of bit balling is higher.

An embodiment wherein there are more axial cutters provided than shearing cutters is preferred for drilling harder earth formations.

5 In an advantageous embodiment, one or more of the shear cutters is provided with a pre-cut flat surface essentially parallel to the plane perpendicular to the longitudinal axis. Even though there are provided axial cutters for taking the axial percussive force, the shear cutters also take part of the impact. Due to the pre-cut  
10 flat surface, the impact stress concentration on the shear cutters is reduced and as a result they do not break as soon as shear cutters that do not have a pre-cut flat surface. A natural wear flat has been found not to be sufficiently flat to effectively reduce the impact  
15 stress concentration, because during percussive operation of the drill bit the shear cutters tend to break in a rough fashion rather than form an effective wear flat.

In an advantageous embodiment, the percussion drill bit further comprises:

- 20 - a plurality of blades protruding from the drill bit;  
- a plurality of flow channels stretching along the drill bit in a substantially radial direction whereby the successive flow channels are formed between two adjacent blades;

25 and wherein the shear cutters are provided in rows on the leading edges of the blades with respect to the direction of rotary motion whereby each row of shear cutters has a flow channel associated with it for running a fluid through and thereby removing cutting debris accumulating  
30 in front of each row of shear cutters.

Herewith, so called bit balling, whereby rock flour and rock chips ploughed in front of the shear cutters mix with drilling fluid such as water, oil or mud to form a paste in the bottom of the bore hole is avoided, because  
35 the substantially radial flow channel is fully effective



in removing cutting debris accumulating in front of the row of shear cutters. Bit balling is undesired, since the resulting paste takes the weight of the bit instead of the underlying rock.

5 Bit balling is even better avoided in an embodiment where the axial cutters are provided with respect to the direction of rotary motion in a trailing position behind each row of shear cutters and ahead of the subsequent  
10 neighbouring flow channel that is associated with the next row of shear cutters of the next blade. Any bit balls formed under the axial cutters will end up in the trailing flow channel.

The above given object of the invention is also achieved by provision of a drilling system for drilling a  
15 borehole in an earth formation, comprising a drill string provided with a percussion drill bit according to one or more of the embodiments described above, the drilling system further comprising:

- first drive means for rotating the drill bit in the  
20 borehole so as to induce a scraping movement of the shear cutters along the borehole bottom; and
- second drive means for inducing repetitive axial percussive impacts on the drill bit in a direction having a component along the axis of the drill bit in the  
25 borehole so as to induce at least the axial cutters to exert a percussive force to the borehole bottom.

The drill bit or drilling system provided with shear cutters having the pre-cut flat surface has been found to cause fewer stick-slip torsional vibration modes in the  
30 drilling system, whereby the bit is hammered to a standstill into the earth formation while the drill string is twisted by the surface rotary drive until it abruptly releases with relatively high rotational speed. Such a stick-slip torsional vibration repeats  
35 periodically and the high rotational speed associated

with the stick-slip torsional vibration can severely damage the cutters on the drill bit.

An objective of the invention is further achieved in a method of drilling a bore hole into a subterranean earth formation, comprising the steps of providing a  
5 drilling system in accordance with one of the above defined embodiments, placing the drill bit against the subterranean earth formation that is to be drilled, exercising a rotary motion about the axis while  
10 maintaining a force on the drill bit against the earth formation in the axial direction, and intermittingly providing percussive strikes on the drill bit.

The invention will now be illustrated by way of example, with reference to the accompanying drawing wherein  
15

FIG. 1a shows a perspective view of a 6" 3-blade percussion drill bit in accordance with the invention;

FIG. 1b shows a top view of the bit face of the percussion drill bit shown in FIG. 1a;

20 FIG. 2 shows a schematic cross section of the cutter arrangement;

FIG. 3a shows a perspective view of a 6" 4-blade percussion drill bit in another embodiment of the invention;

25 FIG. 3b shows a top view of the bit face of the percussion drill bit shown in FIG. 3a;

FIG. 4 is a graph showing recessing variation over consecutive tracks on a 6" bit face;

30 FIG. 5 shows a top view of an 8" bit face according to still another embodiment of the invention, having 8 blades; and

FIG. 6 schematically shows different shear cutters having pre-cut wear flats.

In the figures, like parts carry identical reference  
35 numerals.

A perspective view of a 3-blade percussion drill bit in accordance with the invention is shown in FIG. 1a. The drill bit comprises a shank 1 stretching longitudinally about a central longitudinal axis of the drill bit, which shank can be especially adapted to fit inside a drill string. The rearward end of the shank is connected to a striking surface 2 to receive impacts from a percussive hammer, preferably a reciprocative piston hammer (not shown). The forward end of the shank is connected to a drilling head 3. The shank 1 is provided with a plurality of splines 4, running essentially longitudinally along the shank 1. The splines 4 serve to rotationally couple the drill string and the shank 1, so that the drill bit is operable by applying both axially directed percussive impacts on the drill bit and rotary motion about the central longitudinal axis.

Referring now to FIGs. 1a and 1b, the drilling head 3 is provided with three blades 61, 62, and 63 that protrude from the drill bit. The areas between the blades 61, 62, 63 are recessed with respect to the blades and thus form flow channels 71, 72, 73. The flow channels 71, 72, 73, essentially run radially along the drilling head 3.

A central passage way 8 is provided in the drilling head 3 for passing of flushing fluid. In addition of or instead of the central passage way 8, passage ways 81, 82, 83, can be provided in the flow channels 71, 72, 73 between the blades 61, 62, 63. The passage ways are all connected to a central longitudinal bore (not shown) running through the shank 1.

In hydro-carbon well drilling operations, the drill string is conventionally rotated in clock-wise direction. Arrows 5 in FIGs. 1a and 1b depict the direction of rotary motion that, in operation, is applied to the drill bit.

The blades 61, 62, 63 thus each have a leading edge 91, 92, 93, with respect to the direction of rotary motion 5. Shear cutters 9 are provided in a row on the leading edge 91, 92, 93 of each respective blade 61, 62, 63. Each row of shear cutters 9 has a flow channel associated with it directly in front of the row of shear cutters 9 with respect to the direction of rotary motion 5.

Behind each row of shear cutters 9, thus in a trailing position with respect each row of shear cutters 9, axial cutters 10, 11, are provided on the blades 61, 62, 63.

The shear cutters 9 are recessed with respect to the axial cutters 10, 11, such that the axial cutters 10, 11 impact on the rock in the bottom of the bore hole during percussive impacts before the shear cutters 9 do. In particular, shear cutters positioned on a certain radial distance from the central longitudinal axis are recessed with respect to the axial cutters that are located on approximately the same radial distance.

FIG. 2 depicts a schematic representation of the cutter arrangement in accordance with the invention, as seen in a tangential cross section. As in the previous figures, arrow 5 depicts the direction of rotary motion that, in operation, is applied to the drill bit. Visible are one of the blades 6 and its leading edge 91 with respect to the direction of rotary motion, which blade protrudes downwardly from the drill head and accommodates cutters 9 and 10. A shear cutter 9 is provided on or adjacent to the leading edge 91. Behind the shear cutter 9 in relation to the direction of rotary movement 5, is an axial cutter 10.

The shear cutters 9 have a shape optimised for scraping along the bottom of the bore hole and thereby shearing pieces of the earth formation from the bottom of

the bore hole. The axial cutters 10, 11, have a shape optimised for axially indenting the earth formation in the bottom of the bore hole and thereby possibly crushing the earth formation.

5       As a result of the axial percussive impacts, the formation 13 underneath the axial cutter 10 crushes. The axial cutter 10 is depicted to penetrate into the earth formation 13 by a depth  $d_1$ . The shear cutter 9 is recessed with respect to the axial cutter 10 so that its  
10       penetration depth into the earth formation,  $d_2$ , is less than that of the axial cutter 10 by an amount of  $r$ . As a result of the recessed arrangement of the shear cutter 9 with respect to the axial cutter 10, in operation the  
15       axial cutter first engages a fresh part of the bore hole bottom on a downward percussive movement of the drill bit. The shear cutter 9 does not engage with the earth formation before the axial cutter 10 has indented the  
20       earth formation over a depth  $r$ . At this point, the strongest part of the percussive impact has already been received by the axial cutter 10, and therefore the shear  
25       cutter 9 undergoes less percussive impact forces than it would have when it would have engaged with the earth formation at the same time as, or earlier than, the axial cutter 10. Herewith the operational lifetime of the  
30       cutters is sustained as much as possible.

      Towards the end of the percussive impact, the axial cutters 10, 11 and the shear cutters 9 both are in contact with the earth formation 13, so that the shear cutters 9 can efficiently shear-cut the earth formation and scrape  
30       off cutting debris 19. As the bit rotates, the shear cutters 9 scrape along the bottom hole surface and build up rock flour and chips from the cutting debris and drilling fluid. The rock flour and chips are pushed in front of the shear cutters 9 where there is preferably a  
35       flow channel 7 with flushing fluid running through it in

an essentially radially outward direction. From there, the scraped cutting debris is flushed to the bore hole annulus and removed from the bottom hole area.

5       FIG. 3a shows a perspective view, and FIG. 3b a top  
view, of a variant of the drill bit of the invention  
having four blades 6 and consequently four flow  
channels 7. In other respects, this variant is similar to  
the one shown in FIGs. 1a and 1b. In particular, the  
10       recessed arrangement of the shear cutters 9 on the  
leading edges of the blades with respect to the axial  
cutters 10, 11 that are in a trailing position with  
respect to the rows of shear cutters 9, is similar to the  
first discussed embodiment.

15       The various concentric dot-dash lines in FIG. 3b  
connect groups of axial cutters and shear cutters that  
are considered to be positioned on respective tracks. The  
tracks are numbered tr1 to tr6 starting furthest away  
from the central axis.

20       The amount of recessing of the shear cutters  
preferably varies from track to track, depending on the  
amount of rock that is removed per cutter in each track.  
Generally, close to the gauge of the bit (corresponding  
to lower track numbers) the cutters have to remove more  
formation per cutter since the area of each track  
25       increases with distance from the central axis whereas the  
number of cutters present in that track in many bit  
designs does not increase in the same amount. For this  
reason, on average over time, the outer cutters undergo  
more rock penetration than the cutters closer to the  
30       central axis of the bit. The recessing of the shear  
cutters can be increased accordingly, so that the time-  
averaged penetration of the shear cutters is the same in  
each track either in absolute value of  $d1$  or relative to  
 $d2$ , whichever is desired.

A typical recessing distribution for the 6" bit shown in FIG. 3 is depicted in FIG. 4, for a case where the rate of penetration is to be 12 m/hr, and the percussive frequency is 25 Hz. The shear cutters in the outer most track, having track number 1, are recessed by 0.66 mm versus 0.40 mm in the sixth track.

In general, this distribution of recess values over the tracks can be based on average axial cutter penetration estimates, made in the following way. For a specified rate of penetration of the drill bit, the quantity of rock to be removed in each track is known. Since the number of axial cutters is known, the amount of removed rock per axial cutter is also known. It is thereby assumed that most rock is removed by the percussive impacts which has a known frequency.

The diameter of the outer periphery of the percussion drill bits discussed above in FIGs. 1a and 1b, and FIGs. 3a and 3b, is 6", corresponding to approximately 15 cm. An example of an 8" (corresponding to approximately 20 cm outer diameter) bit face is depicted in FIG. 5.

The various concentric dot-dash lines in FIG. 5 connect groups of axial cutters and shear cutters that are considered to be positioned on respective tracks.

The embodiment shown in FIG. 5 is based on eight blades 6 and a corresponding number of flow channels 7. Each flow channel 7 is provided with a passage way 81 for allowing entry of flushing fluid into the respective flow channel. Since this bit face of FIG. 5 has a larger diameter than the ones shown in FIGs. 2 and 3, a larger number of shear cutters 9 and axial cutters 10,11 can be accommodated.

In the above described percussion drill bits depicted in FIGs. 3a and 3b and FIG. 5, the shear cutters in a first said row of shear cutters are positioned at

mutually different radial positions than the shear cutters in a second said row of shear cutters on another blade. This way, the gaps left between adjacent shear cutters in one row are covered by the shear cutters in a next row on a different blade when the drill bit is rotated. Ideally, the circular paths of the collection of shear cutters slightly overlap such that a continuous band of shear cutting is achieved over a majority of the area in the bore hole bottom surface.

In the above shown embodiments, the axial cutters 10 are each formed of an axial cutter shank 16 which at least on one side is provided with a hemispherical or dome shaped cutting surface 17. The cutter is made of a hard material, for which tungsten carbide is a suitable material. Optionally, the cutter can be provided with a layer of polycrystalline diamond thus forming a PDC axial cutter.

In the examples shown in FIGs. 1a and 1b, FIGs. 3a and 3b, and FIG. 5, the outermost axial cutters 11 are PDC axial cutters and the other axial cutters 10 are tungsten carbide axial cutters. Thus, in these bit faces the outer most axial cutters 11 are harder than the remaining axial cutters 10.

The shear cutters 9 shown above are PDC cutters having a shear cutter shank 14 made of a hard material, for which tungsten carbide is suitable. The rake surface facing the associated flow channel 71, is covered with a layer 15 of polycrystalline diamond. Such a shear cutter having a polycrystalline diamond cutting surface is known as a polycrystalline diamond compact cutter, or PDC cutter. The shear cutter is provided with a pre-cut flat surface stretching essentially perpendicular to the central longitudinal axis of the drill bit and essentially parallel to the bottom hole surface of the earth formation 13.



In order to reduce the impact stress concentration acting on the shear cutters, the shear cutters 9 in the above described examples are provided with a pre-cut wear surface. These pre-cut wear surfaces are also beneficial in reducing the tendency to excite so-called slip-stick torsional vibrations in the drilling system.

FIG. 5 schematically shows the provision of the pre-cut flat surface on these shear cutters for different pre-cutting depths of 1 mm, 2 mm and 3 mm. The pre-cutting depth corresponds to the normal distance between the pre-cut surface and the summit point 18 where the shear cutter shank outer shell and the rake surface come together. The back-rake angle of each of these shear cutters is  $40^\circ$  as an example, but any angle smaller than  $90^\circ$  can be applied. It can be seen that the pre-cut flat surface area increases as the pre-cutting depth increases. Preferably, the pre-cutting depth is between 1 and 3 mm.

In operation, the percussion drill bit is incorporated in a drilling system whereby the percussion drill bit is held by a drill sting. The drilling system further comprises:

- first drive means for rotating the drill bit in the borehole so as to induce a scraping movement of the shear cutters along the borehole bottom; and
- second drive means for inducing a longitudinal reciprocal movement of the drill bit in the borehole so as to induce at least the axial cutters to exert a percussive force to the borehole bottom, which first and second drive means are both operated simultaneously. The second drive means are preferably formed by a hammer, more preferably a reciprocative piston hammer. During a drilling operation, a drilling fluid is pumped through the drill string which is in fluid connection with the passages 8, 81, 82, 83. Suitable drilling fluids are mud,

water, oil or foam, and can vary in dependence of the type of formation to be drilled.

In order to further assist the flushing of cutting debris through the flow channels, the rake surface of each shear cutter can have a secondary inclination relative to the radial direction of the drill bit, the secondary inclination being such that the rake surface pushes drill cuttings from the rock formation in radially outward or radially inward direction.

Field trial 1

Using a drill bit with a cutter pattern corresponding to the cutter pattern depicted in FIG. 5, a bore hole was percussively drilled at a depth of 3.6 km through black gneiss, which is a very hard and abrasive rock. Counting radially inwards, the lay out of the drill bit is summarised in the following table.

Track ID	Shear PCD	Carbide dome	PDC dome	Recess r
tr1	4	0	16	0
tr2	4	0	4	0
tr3	4	4	0	0
tr4	4	4	0	0
tr5	4	4	0	0
tr6	4	4	0	0.25 mm
tr7	4	4	0	0.50 mm
tr8	2	2	0	0
tr9	2	2	0	0
tr10	2	2	0	0
tr11	0	1	0	n.a.
tr12	0	1	0	n.a.
tr13	0	0	1	n.a.

The shear cutters in tracks 1 to 5 and 8 to 10 were not recessed with respect to the axial cutters in these

tracks. The shear cutters in track 6 were recessed by  
 $r = 0.25$  mm with respect to the axial cutters in that  
track. The shear cutters in track 7 were recessed by  
 $r = 0.50$  mm with respect to the axial cutters in that  
track.

After two hours of drilling, the shear cutters in  
track 7 were largely undamaged, while they were heavily  
damaged in the remaining tracks. The shear cutters in  
track 6 were less heavily damaged than those in the  
remaining tracks, but in worse condition than those in  
track 7.

Surprisingly, not only the shear cutters but also the  
axial cutters in track 7 were less worn than the axial  
cutters in the other tracks.

The percussion drill bits shown and described above  
have 6" and 8" outer diameters by way of example. It will  
be understood that other diameters can be applied in a  
similar fashion. Likewise, the invention is not limited  
by the number of blades shown. Any number of blades can  
be provided.

12. 06. 2003

TS 6436 EPCC L A I M S

1. A percussion drill bit for drilling into a subterranean earth formation, the drill bit having a central longitudinal axis and being operable by applying repetitive axial percussive impacts on the drill bit in a direction having a component along the axis and by applying rotary motion about the axis relative to the earth formation, the drill bit comprising:

- one or more axial cutters for predominantly axially cutting the subterranean earth formation in response to the axial percussive impacts;

- one or more shear cutters for predominantly shear cutting the subterranean earth formation in response to the rotary motion; whereby

there is a first shear cutter of the one or more shear cutters, and whereby one or more of the axial cutters are arranged with respect to at least the first shear cutter to engage with the subterranean earth formation earlier during a percussive impact than at least the first shear cutter.

2. The percussion drill bit of claim 1, wherein the one or more axial cutters are arranged with respect to the first shear cutter to penetrate on average deeper into the earth formation than the first shear cutter in each percussive movement, preferably at least 1.5 times deeper, more preferably at least 2 times deeper.

3. The percussion drill bit of claim 1 or 2, wherein the first shear cutter is arranged in a first annular track about the central axis, the first annular track having a radial width corresponding to the radial width of the first shear cutter, whereby the one or more axial cutters are arranged in the first annular track.

4. The percussion drill bit of any one of the previous claims, wherein the one or more axial cutters and the first shear cutter each have an impact point, defined as the part of the cutter that serves to firstly engage with the earth formation on an axial percussive impact, whereby at least the impact point of the first shear cutter is recessed by an amount of  $r$  in respect of the impact points of the one or more axial cutters.

5. The percussion drill bit of claim 3 and 4, wherein there is a second shear cutter arranged in a second annular track about the central axis, the second annular track having a radial width corresponding to the radial width of the second shear cutter, whereby one or more axial cutters are arranged in the second annular track, whereby the impact point of the second shear cutter is recessed in respect of the impact points of the one or more axial cutters in the second annular track by an amount larger than  $r$ .

6. The percussion drill bit of claim 5, whereby the second annular track is radially further outward with respect to the central axis than the first annular track.

7. The percussion drill bit of claim 4, 5, or 6, wherein  $r > 0.25$  mm, and preferably  $r \geq 0.50$  mm.

8. The percussion drill bit of any one of the previous claims, wherein the axial cutters have dome shaped or essentially hemispherical shaped cutting surfaces.

9. The percussion drill bit of any one of the previous claims, wherein the shear cutters have a rake surface facing the flow channel associated with it at a back-rake angle of less than  $90^\circ$  wherein the back-rake angle is defined as the angle between the projection of a line perpendicular to said rake surface on a plane defined by said central longitudinal axis of the drill bit and the tangential direction of rotary motion, and a plane perpendicular to said longitudinal axis.

10. The percussion drill bit of any one of the previous claims, wherein one or more of the shear cutters is provided with a pre-cut flat surface essentially parallel to the plane perpendicular to the central longitudinal axis.

11. The percussion drill bit of any one of the previous claims, further comprising:

- a plurality of blades protruding from the drill bit;
- a plurality of flow channels stretching along the drill bit in a substantially radial direction whereby the successive flow channels are formed between two adjacent blades;

and wherein the shear cutters are provided in rows on the leading edges of the blades with respect to the direction of rotary motion whereby each row of shear cutters has a flow channel associated with it for running a fluid through and thereby removing cutting debris accumulating in front of each row of shear cutters.

12. The percussion drill bit of claim 11, wherein the axial cutters are provided with respect to the direction of rotary motion in a trailing position behind each row of shear cutters and ahead of the subsequent neighbouring flow channel that is associated with the next row of shear cutters of the next blade.

13. The percussion drill bit of any one of the previous claims, wherein the ratio between the number of axial cutters and the number of shearing cutters provided is at least 3:2.

14. Drilling system for drilling a borehole in an earth formation, comprising a drill string provided with a percussion drill bit in accordance with any one of the previous claims, the drilling system further comprising:

- first drive means for rotating the drill bit in the borehole so as to induce a scraping movement of the shear cutters along the borehole bottom; and

- second drive means for inducing repetitive axial percussive impacts on the drill bit in a direction having a component along the axis of the drill bit in the borehole so as to induce at least the axial cutters to exert a percussive force to the borehole bottom.

5 15. Method of drilling a bore hole into a subterranean earth formation, comprising the steps of providing a drilling system in accordance with claim 14, placing the drill bit against the subterranean earth formation that  
10 is to be drilled, exercising a rotary motion about the axis while maintaining a force on the drill bit against the earth formation in the axial direction, and intermittingly providing percussive strikes on the drill bit.

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(42)

TS 6436 EPCA B S T R A C TPERCUSSIVE DRILL BIT, DRILLING SYSTEM COMPRISING SUCH A  
DRILL BIT AND METHOD OF DRILLING A BORE HOLE

A percussion drill bit for drilling into a subterranean earth formation, the drill bit having a central longitudinal axis and being operable by applying repetitive axial percussive impacts on the drill bit in a direction having a component along the axis and by applying rotary motion about the axis relative to the earth formation, the drill bit comprising:

- one or more axial cutters for predominantly axially cutting the subterranean earth formation in response to the axial percussive impacts;
- one or more shear cutters for predominantly shear cutting the subterranean earth formation in response to the rotary motion; whereby there is a first shear cutter of the one or more shear cutters, and whereby one or more of the axial cutters are arranged with respect to at least the first shear cutter to engage with the subterranean earth formation earlier during a percussive impact than at least the first shear cutter.



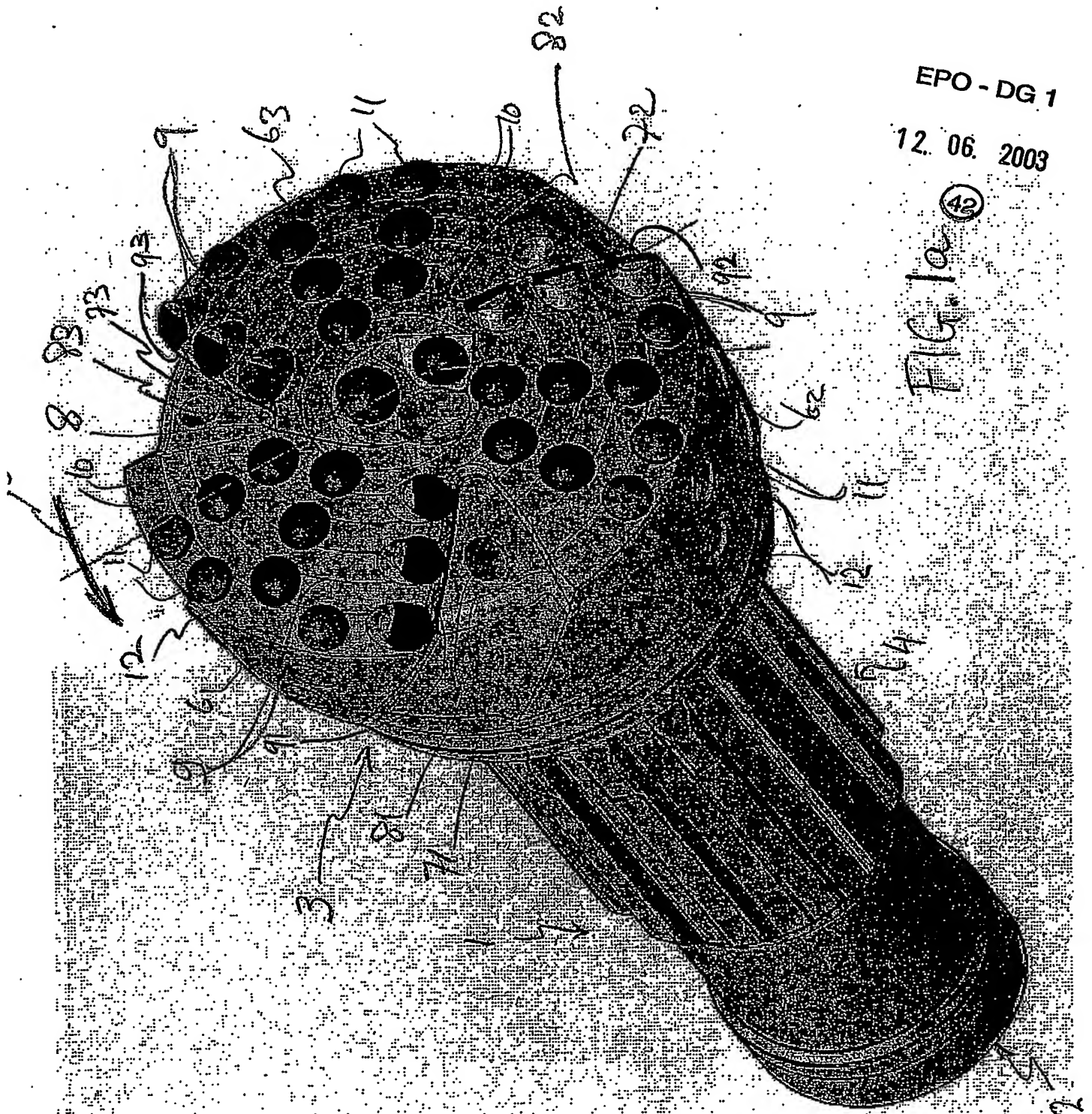
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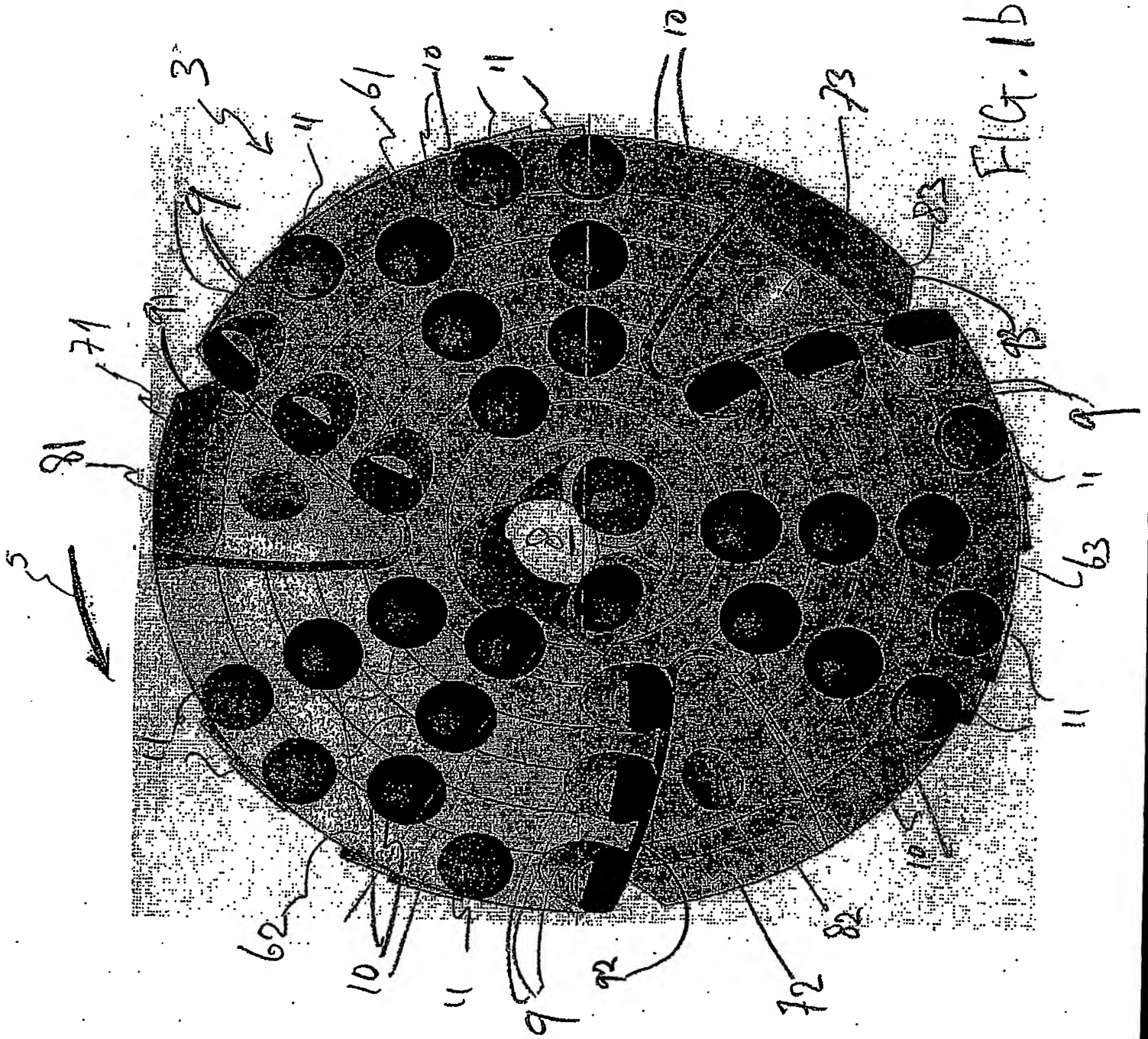
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FIG. 1a



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TS 6436 aPL

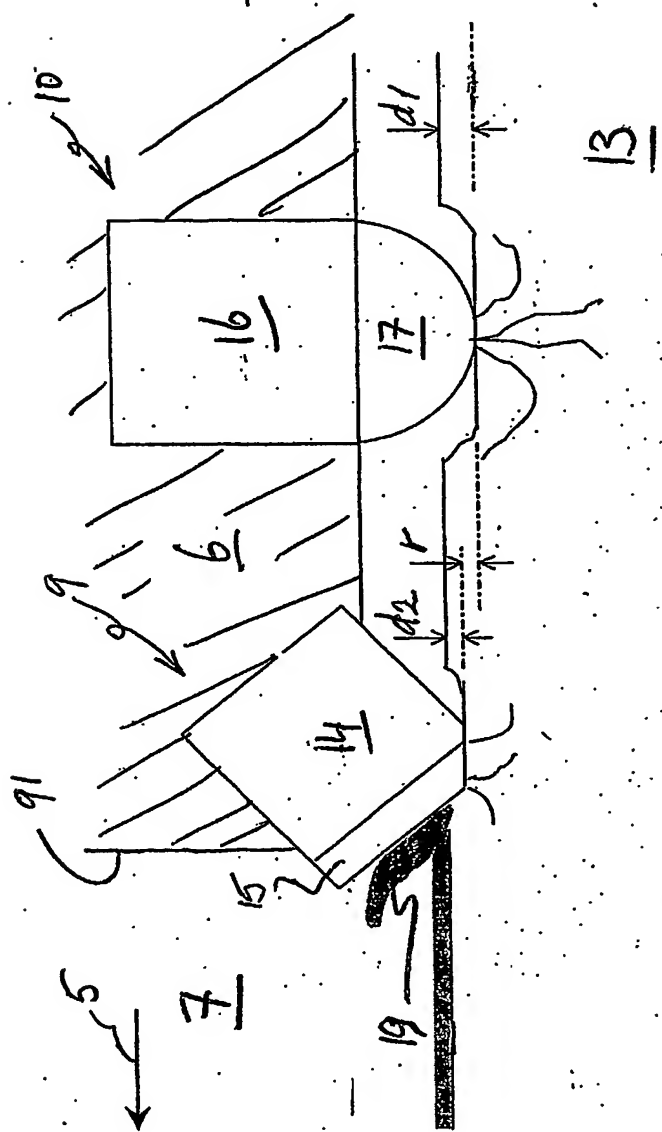


Fig. 2

1,5 6436 epL

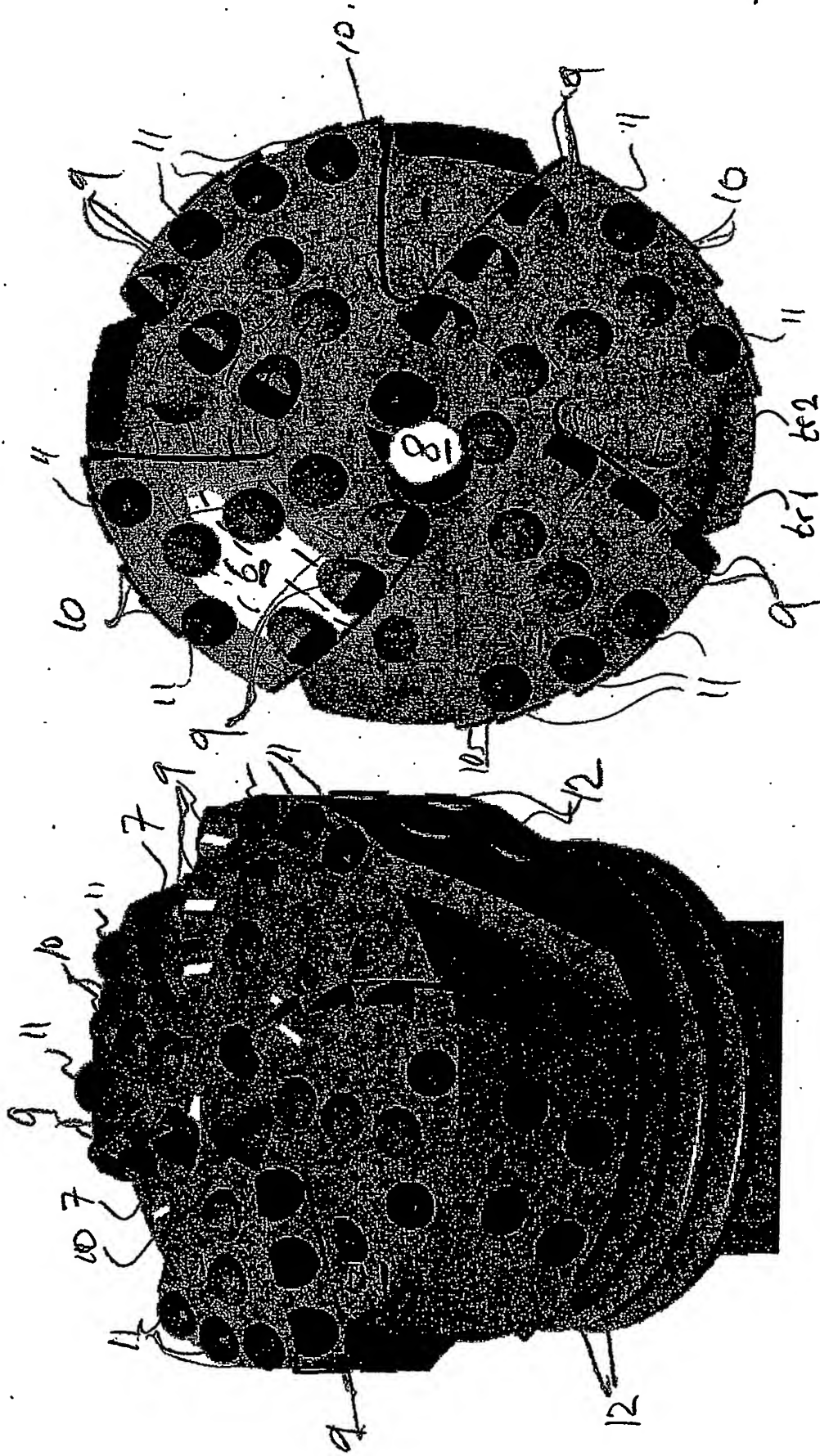
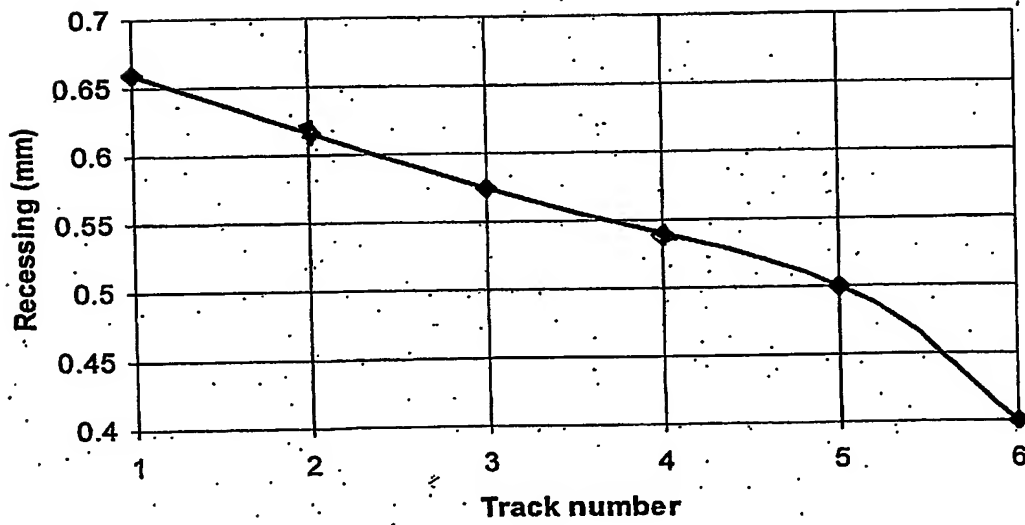


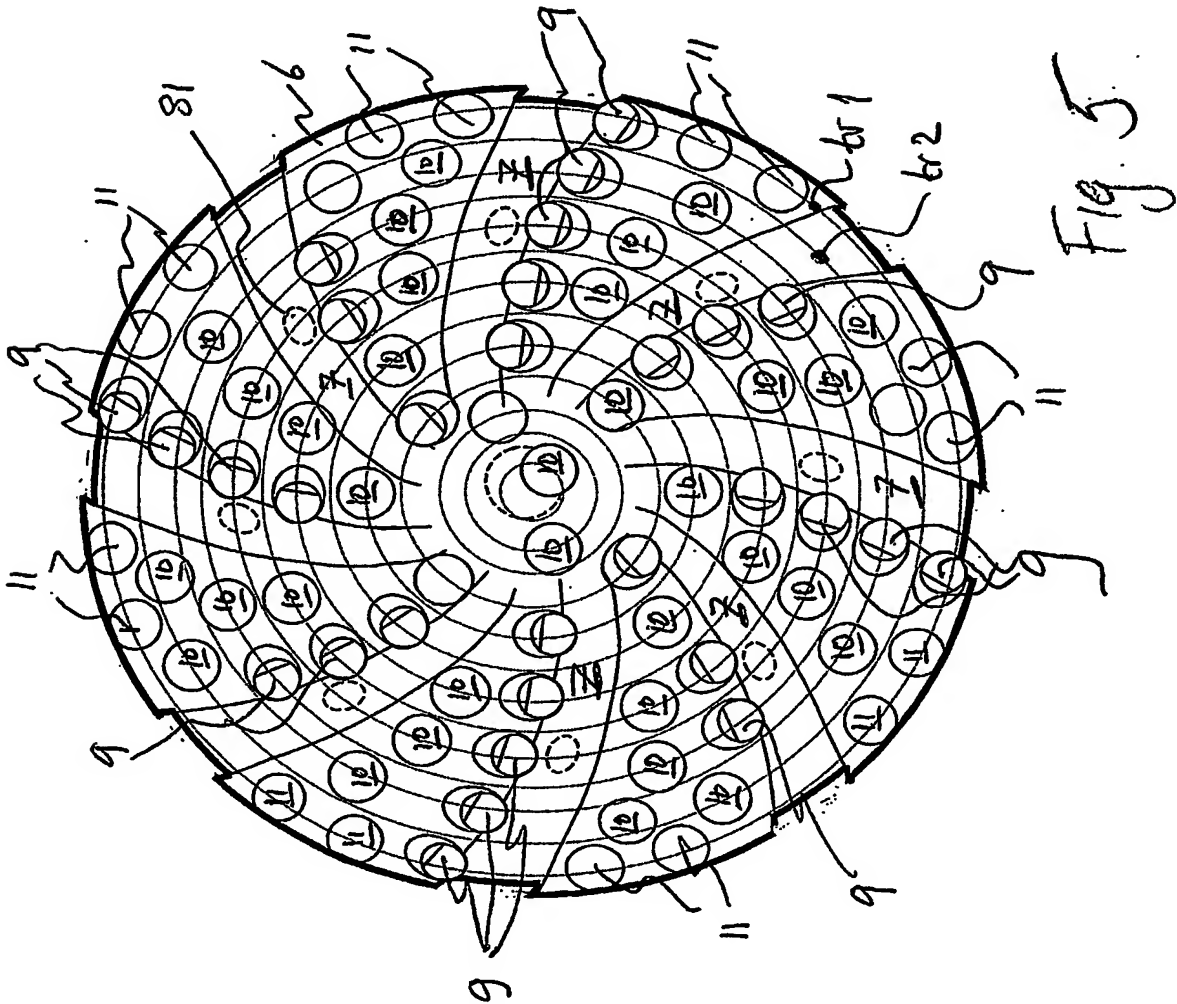
FIG. 3b.

FIG. 3a

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FIG. 4





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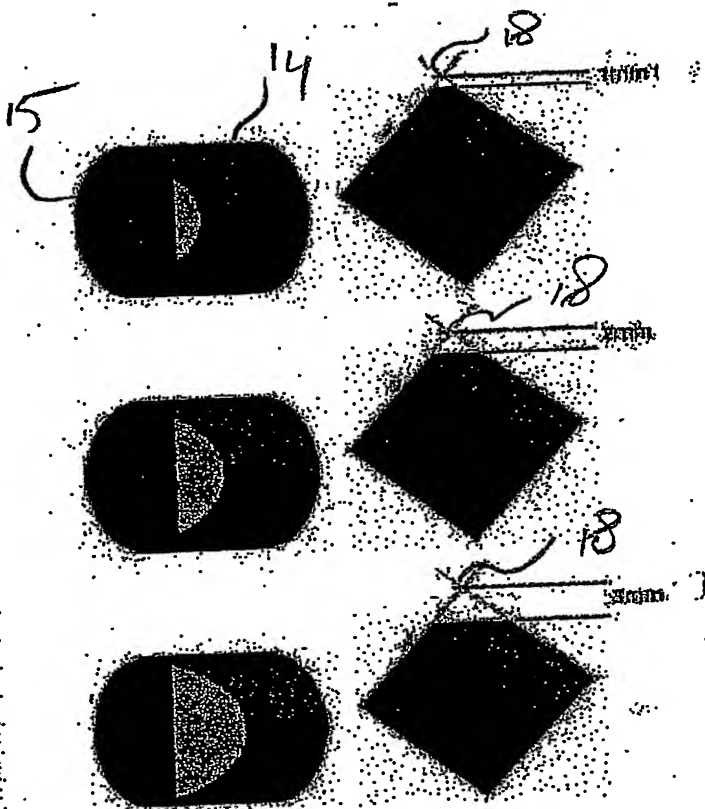


FIG. 8

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